

SEPTEMBER SECTION DINNER MEETING

TUESDAY, SEPTEMBER 11, 2001

"Thermal Protection Materials for Reentry and Planetary Applications"

Sylvia M. Johnson, NASA Ames Research Center, Moffett Field, CA

Thermal protection materials and systems (TPS) are used to protect spacecraft during reentry into Earth's atmosphere or entry into planetary atmospheres. As such, these materials are subject to severe environments with high heat fluxes and rapid heating. Catalytic effects can increase the temperatures substantially. These materials are also subject to impact damage from micrometeorites or other debris during ascent, orbit, and descent, and thus must be able to withstand damage and to function following damage. Thermal protection materials and coatings used in reusable launch vehicles will be reviewed, including the needs and directions for new materials to enable new missions that require faster turnaround and much greater reusability. The role of ablative materials for use in high heat flux environments, especially for non-reusable applications and upcoming planetary missions, will be discussed. New thermal protection system materials may enable the use of sharp nose caps and leading edges on future reusable space transportation vehicles. Vehicles employing this new technology would have significant increases in maneuverability and out-of-orbit cross range compared to current vehicles, leading to increased mission safety in the event of the need to abort during ascent or from orbit. Ultrahigh temperature ceramics, a family of materials based on HfB_2 and ZrB_2 with SiC , will be discussed. The development, mechanical and thermal properties, and uses of these materials will be reviewed.

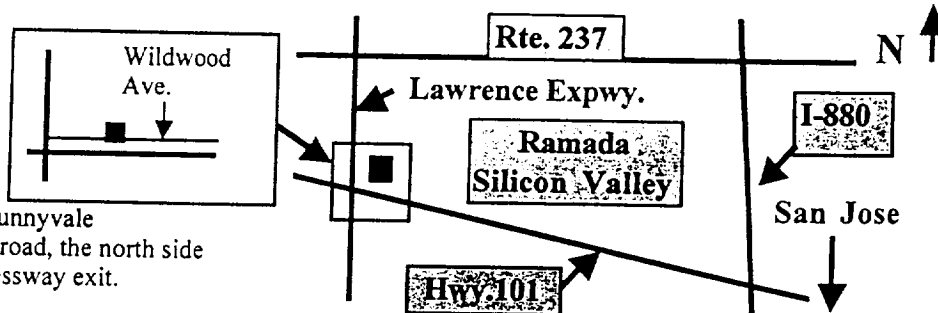
Sylvia Johnson is Chief, Thermal Protection Materials & Systems Branch, NASA Ames Research Center, Moffett Field, California, where she is responsible for technical, personnel, and financial management of over 30 civil servants and contractors involved in research, development, and application of new and improved thermal protection materials for space and planetary missions. Dr. Johnson has a B.Sc. with honors in Ceramic Engineering from the University of New South Wales, Australia (1976), and M.S. (1979) and Ph.D. (1983) degrees in Materials Science from U.C. Berkeley. She has 18 years' experience at SRI International where she gained expertise in the mechanical behavior of ceramics, preceramic polymers, sintering kinetics and phase equilibria, ceramic forming techniques, ceramic processing, forming, and joining techniques, powder synthesis, composite fabrication, degradation of ceramics, and synthesis and processing of high temperature superconductors. Sylvia has co-authored 5 technical articles, has 2 U.S. patents, is active in National American Ceramic Society affairs, has co-chaired four PCRM Meetings, and is Counselor to the Northern California Section of ACerS.

Location:

RAMADA Silicon Valley
1217 Wildwood Ave.
Sunnyvale, Ca 94089
(408) 245-5330

Directions:

The Ramada Silicon Valley is in Sunnyvale on the Wildwood Avenue frontage road, the north side of Hwy. 101 at the Lawrence Expressway exit.



Agenda: Social Hour 6:00-7:00 p.m., Dinner 7:00-8:00 p.m., Technical Presentation 8:00-9:00 p.m.

PLEASE MAKE ALL RESERVATIONS IN ADVANCE!

Make meal arrangements with Dan Day by phone at 925-294-7530 (voice mail) or by e-mail at dday@nrmc.com. Leave your name(s), daytime phone, and meal selection. Make your reservation by Friday, September 7th. Pay at the door.

Dinner cost:	Members/Guests \$20.00 each	Nonmembers \$22.00 each	Students \$5.00 each
Meal Selections:	Chicken Piccata	Vegetarian	



Thermal Protection Materials for Reentry Applications



Structural Ceramics and Ceramic Composites for High-Temperature Applications Conference

United Engineering Foundation
Seville, Spain
October 11, 2001

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Contributors



- NASA Ames Research Center
 - Jim Arnold, Paul Wercinski, James Reuther, Dean Kontinos, Don Ellerby, Bernie Laub, Dan Leiser, Christine Szalai, Joe Hartman
- Elorete at NASA Ames Research Center
 - Michael Gusman, Mairead Stackpoole
- University of New Mexico/Sandia National Laboratories
 - Ron Loehman
 - Paul Kotula, Sandia National Laboratories, Albuquerque





Outline



- Background on Thermal Protection Systems (TPS)
- Thermal Protection Materials and Systems at NASA-Ames Research Center
 - Ames Arc Jet Complex
 - Ablators
 - Ceramics (Shuttle Tiles, Blankets, Coatings)
 - Sharp Leading Edges
 - Safety Benefits
 - UHTC Materials
 - Summary





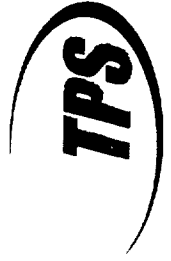
Trans-atmospheric* Vehicles



System	Function
1) Propulsion	Provide Delta V
2) Structure	Provide Form & Connectivity
3) GN&C	Provide Flight Control
4) <i>Thermal Protection (TPS)</i>	<i>Provide Thermal Isolation**</i>

- **Systems analyses have shown that TPS is the second most important vehicle system (behind propulsion) relative to life cycle cost and risk**

* - Reusable Launch Vehicles and Planetary Entry Spacecraft
** - From the hypersonic shock layer



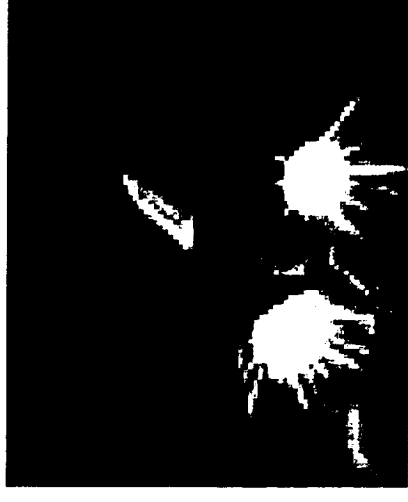
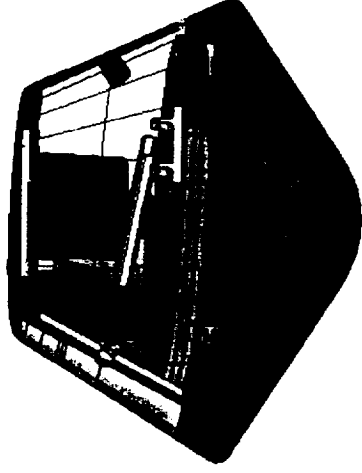


Future Vehicle TPS : Minimize Life Cycle Cost; Maximize Safety

Minimum Vehicle Life Cycle Costs:

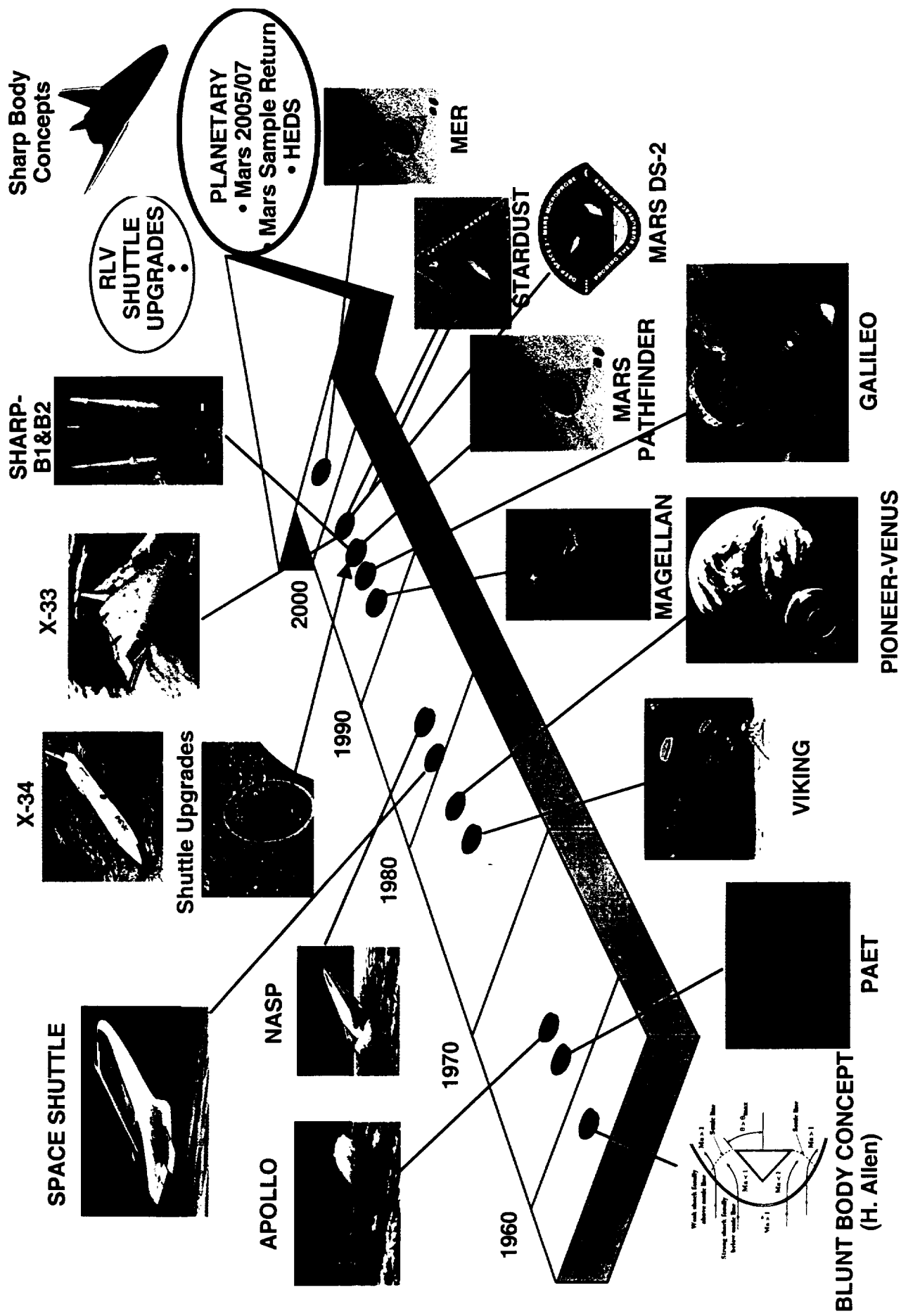
- » Minimum weight & maximum performance (accreage)
 - Very light-weight, very high temperature capability, very efficient insulators
- » Very high thermal gradient materials (leading edges)
- » Low manufacturing costs
 - Billet processing, novel fabrication concepts
- » Low maintenance
 - » - Robust for induced and natural environments, fail safe, enable automated inspection

Spacecraft



Thermal Protection Tiles

NASA Entry Vehicles and Missions Supported by Ames





Ames Arc Jet Complex





Ames Arc Jet Complex



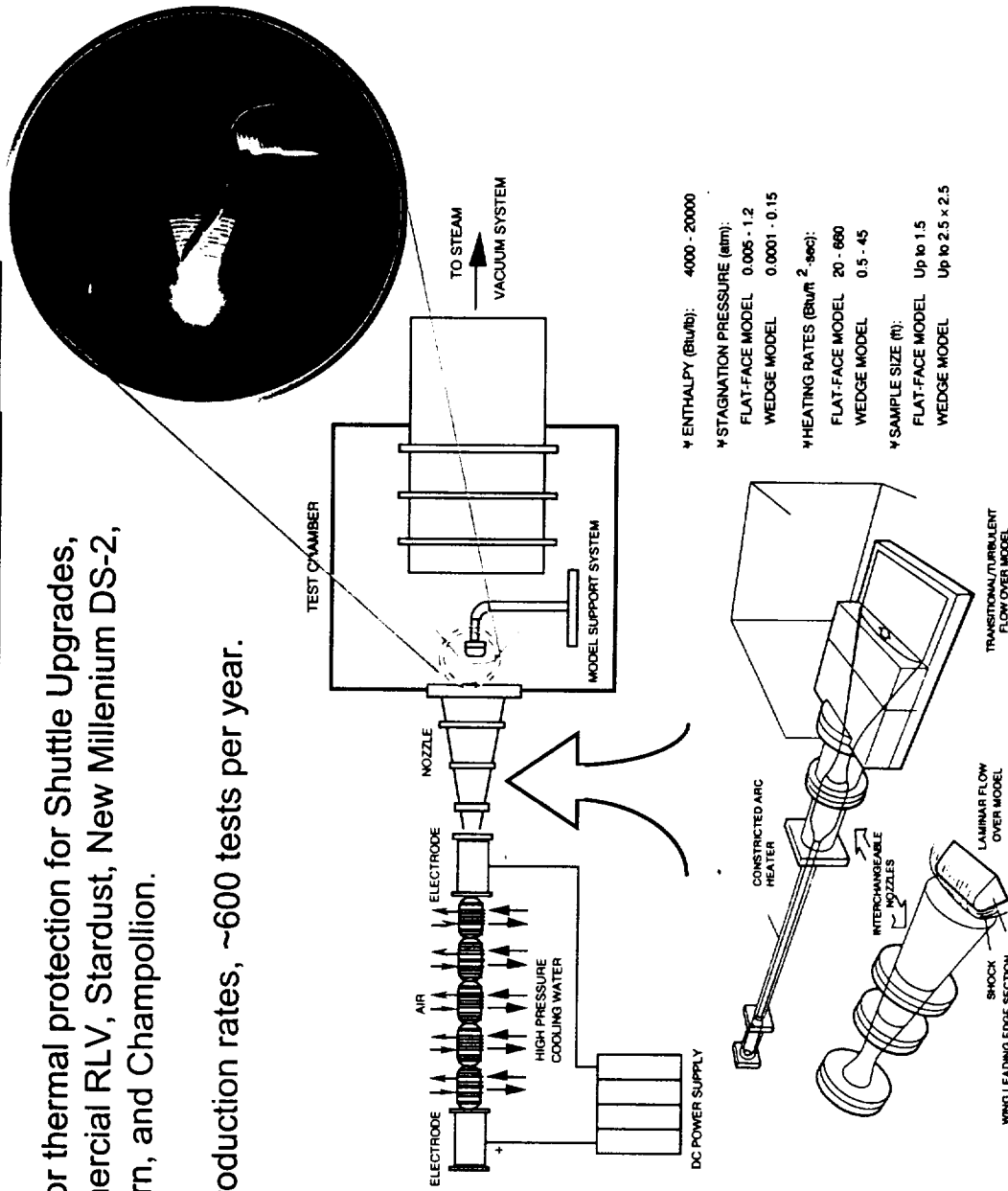
- Produces critical path data for thermal protection for Shuttle Upgrades, X-33, X-34, Future-X, Commercial RLV, Stardust, New Millennium DS-2, Genesis, Mars Sample Return, and Champollion.

- Currently operates at high production rates, ~600 tests per year.

- Continuous plasma flow generated by dc discharge within a constrictor tube.

- Maximum rating: 8000 Vdc at 6000 Amp

- Interchangeable nozzles: (1) conical, and (2) panel test configurations





Perspective on Type of TPS

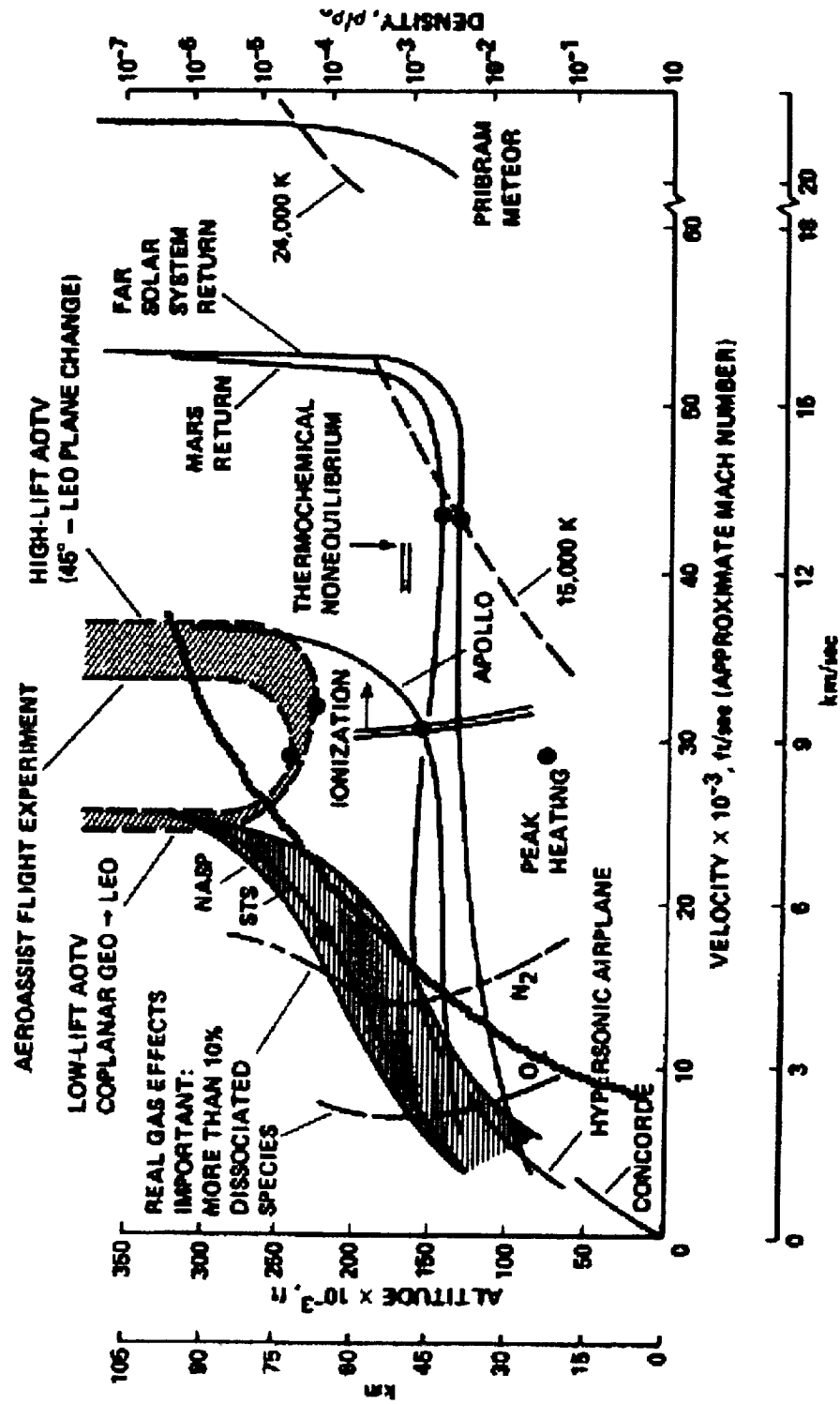


Figure 1-1.- Comparison of vehicle flight regimes in Earth's atmosphere.

Reference: Howe, John T. "Hypervelocity Atmospheric Flight: Real Gas Flow Fields, NASA TM 1249, Nov. 1990.

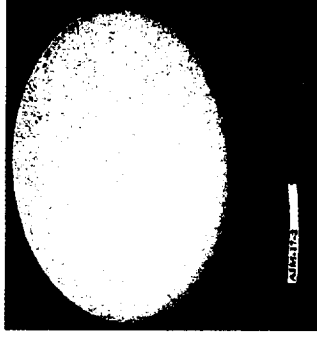
The blue line is an approximation that illustrates the regions where one can employ a reusable TPS vs. the region where an ablative TPS is required due to the severity of the aerothermal environment



Ames' Light Weight Ceramic Ablator Family Ease of Manufacturing and Performance



- SIRCA
 - Silicone Impregnated Refractory Ceramic Ablator
 - For medium heat fluxes
 - Made by infiltrating silicone resin into a silica-based tile
- PICA
 - Phenolic Impregnated Carbon Ablator
 - For high heat fluxes Phenolic resin infiltrated into carbon fiber preform
- APPLICATIONS
 - SIRCA: Mars/Pathfinder, X-34, Mars Exploration Rover, Mars '03 (ARC is making the back interface plate)
 - PICA: Stardust



SIRCA



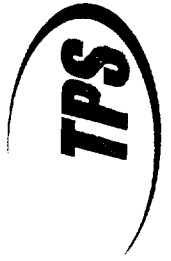
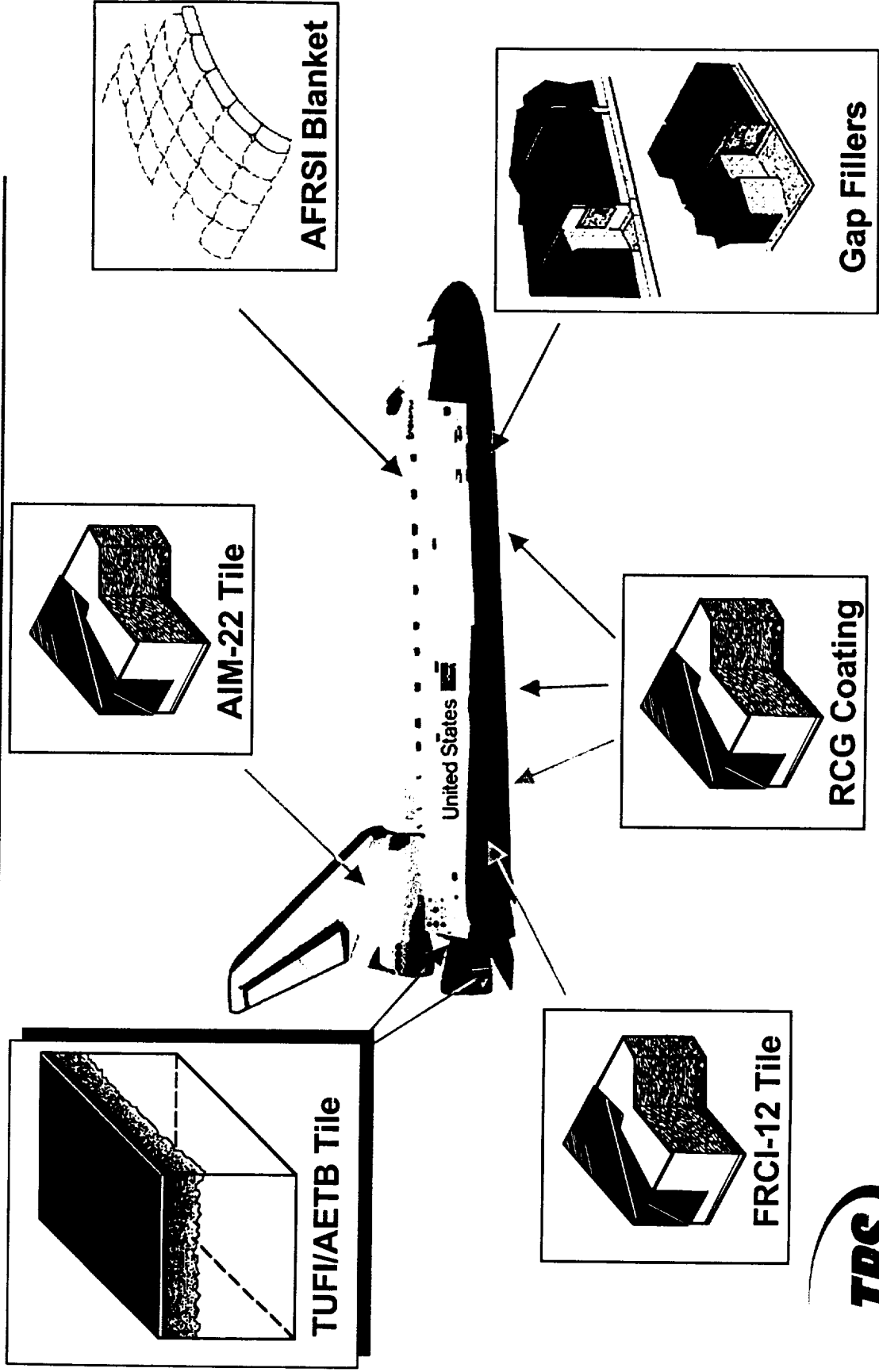
PICA

(Shuttle - low heat flux)





Ames-Developed Thermal Protection Materials Adopted to Date on Shuttle

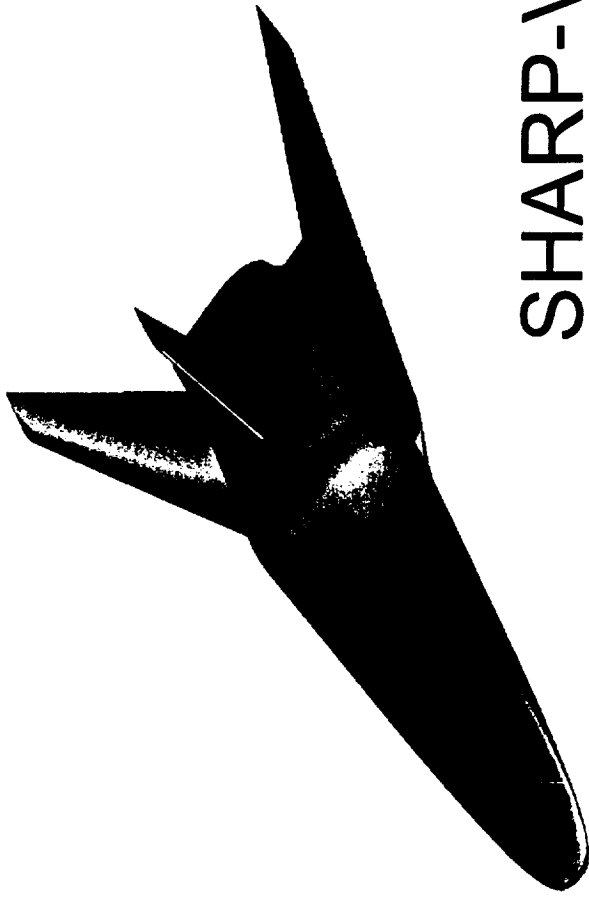




Sharp Leading Edges Provide Increased Safety and Performance



- Reduce propulsion requirements by decreasing drag
- Increase maneuverability
- Increase time during ascent for safe abort to ground
- Increase out-of-orbit cross range which enhances safety by increasing the number of potential landing sites



SHARP-V5



Crew Transfer Vehicle Mission

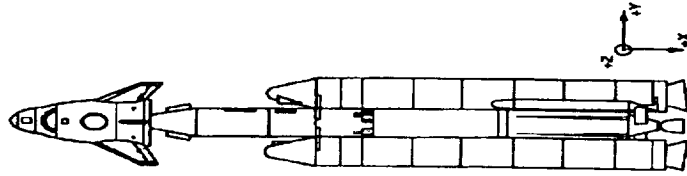
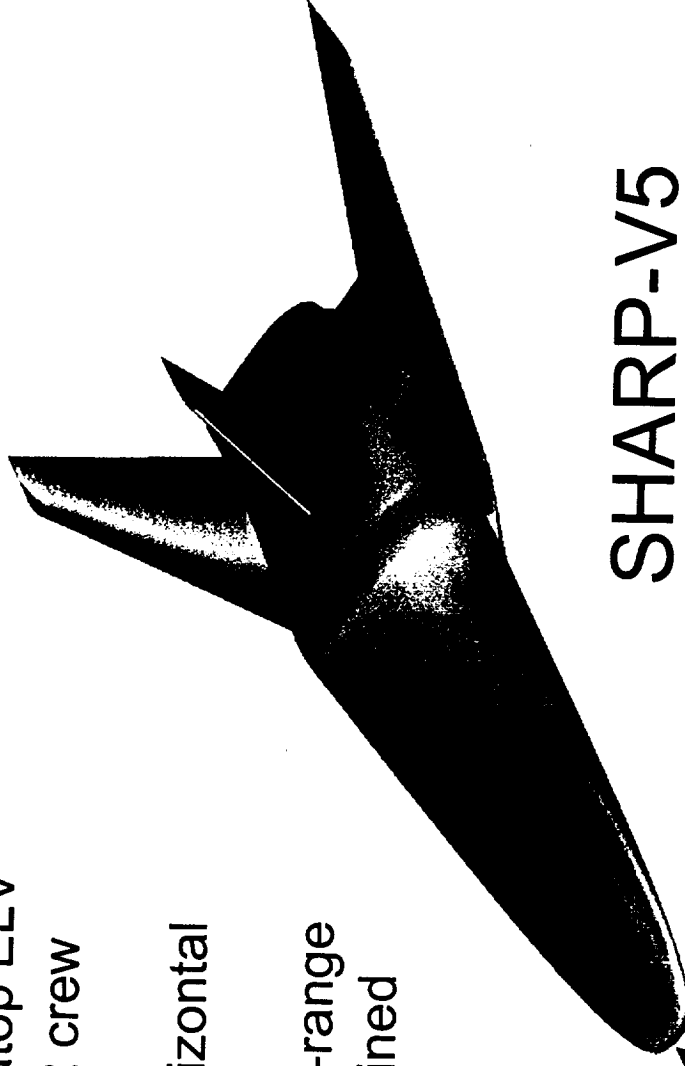


Fig. 1 Then SHUTTLE configuration.

- vertical launch atop ELV
- 8 passengers, 2 crew
- ISS rendezvous
- unpowered, horizontal landing
- maximum cross-range trajectories examined



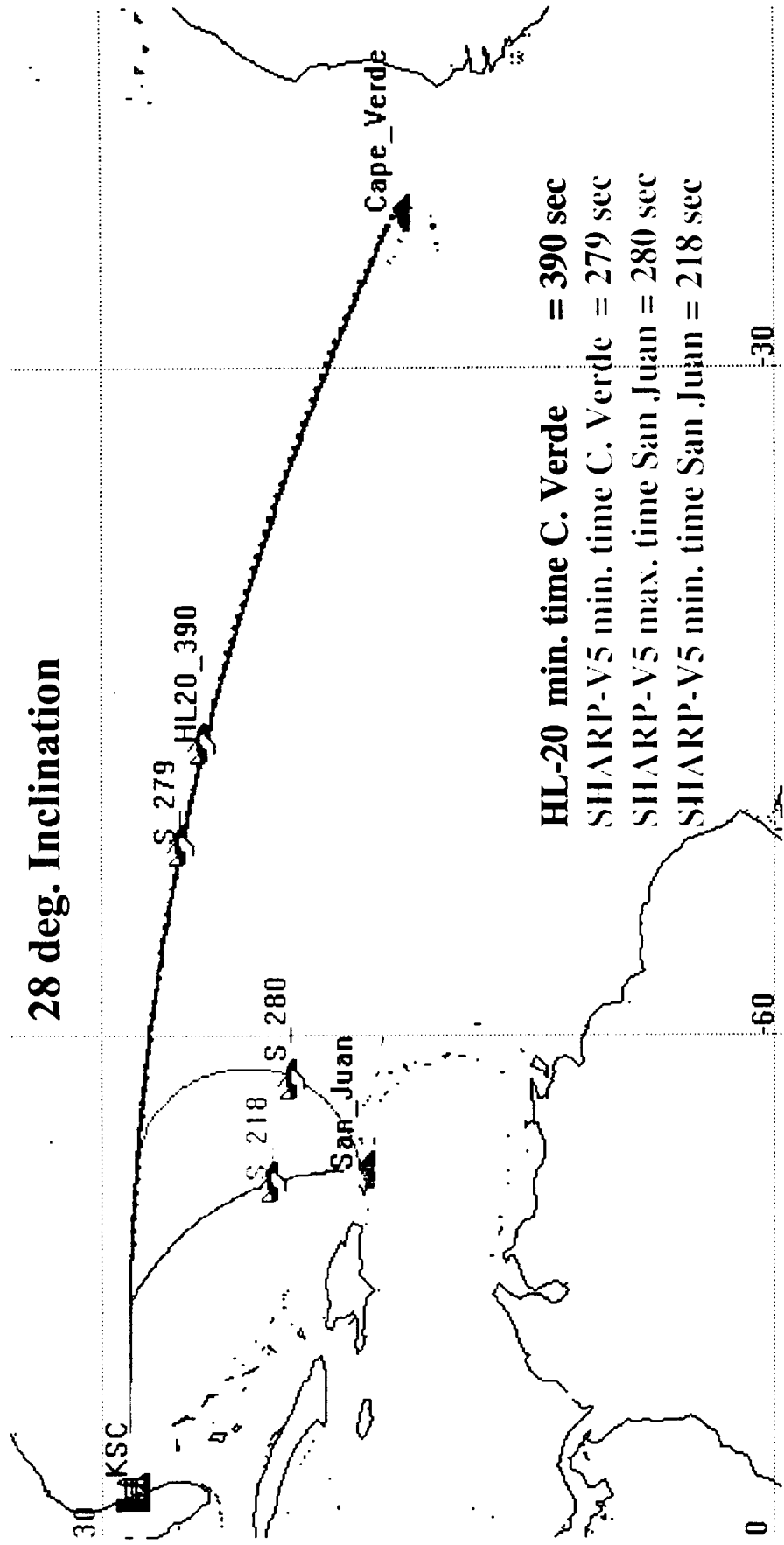
SHARP-V5

Ultra-High Temperature
Ceramic (UHTC) Leading Edge





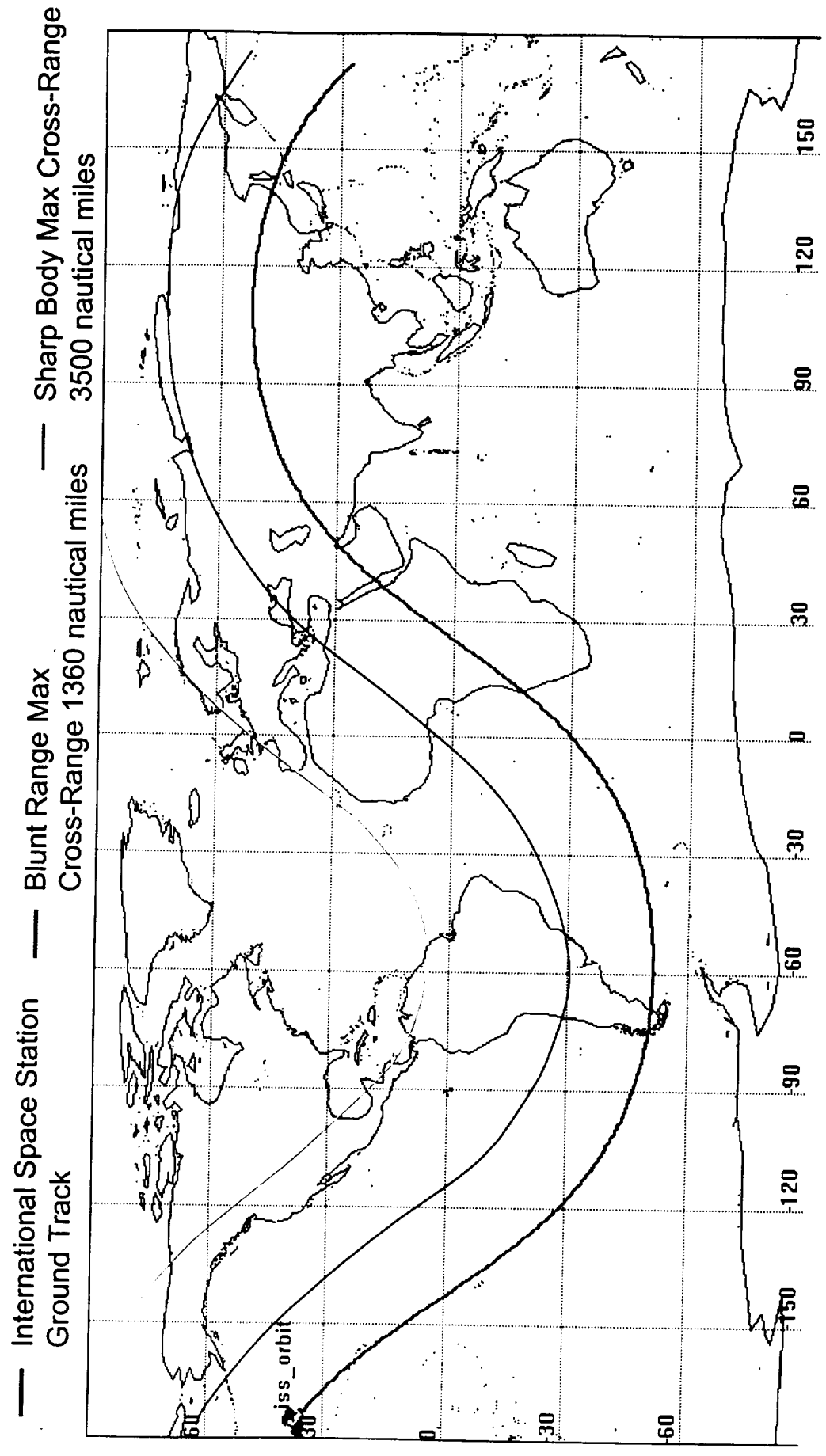
Potential Benefit - Impact On Crew Safety



Results of the SHARP CTV study show the potential of minimizing the need to abort into the ocean by increasing the capability of landing on a runway in the event of a failure during launch. 390 - 218 = 172 seconds improvement.



ISS Ground Track vs. Cross Range

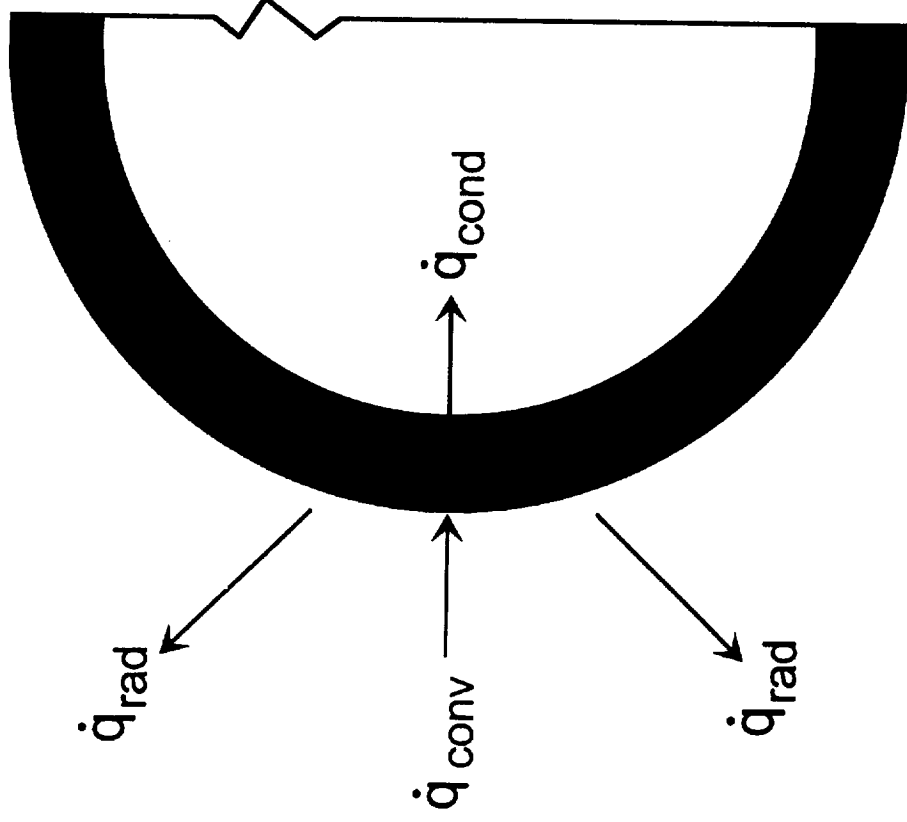




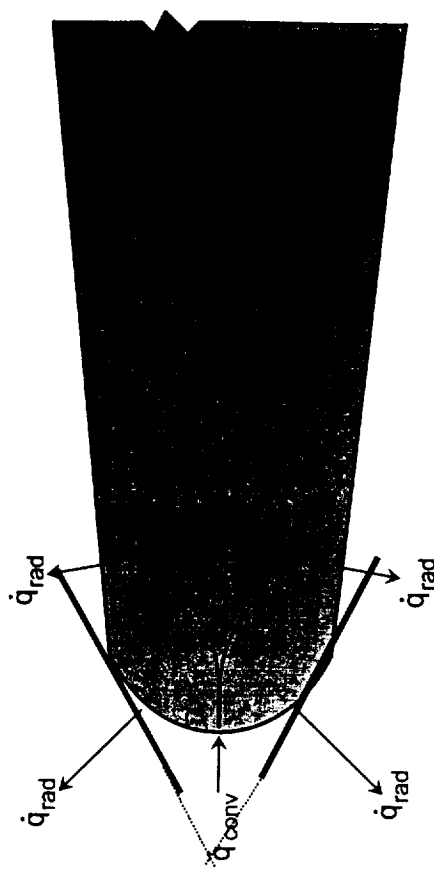
Surface Energy Balance



Please note the Sharp Nose will be redrawn completely to consistently reflect true shape. This does not affect any Export Control issues.

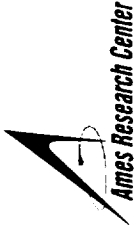


Blunt Nose $\dot{q}_{conv} \approx \dot{q}_{rad}$

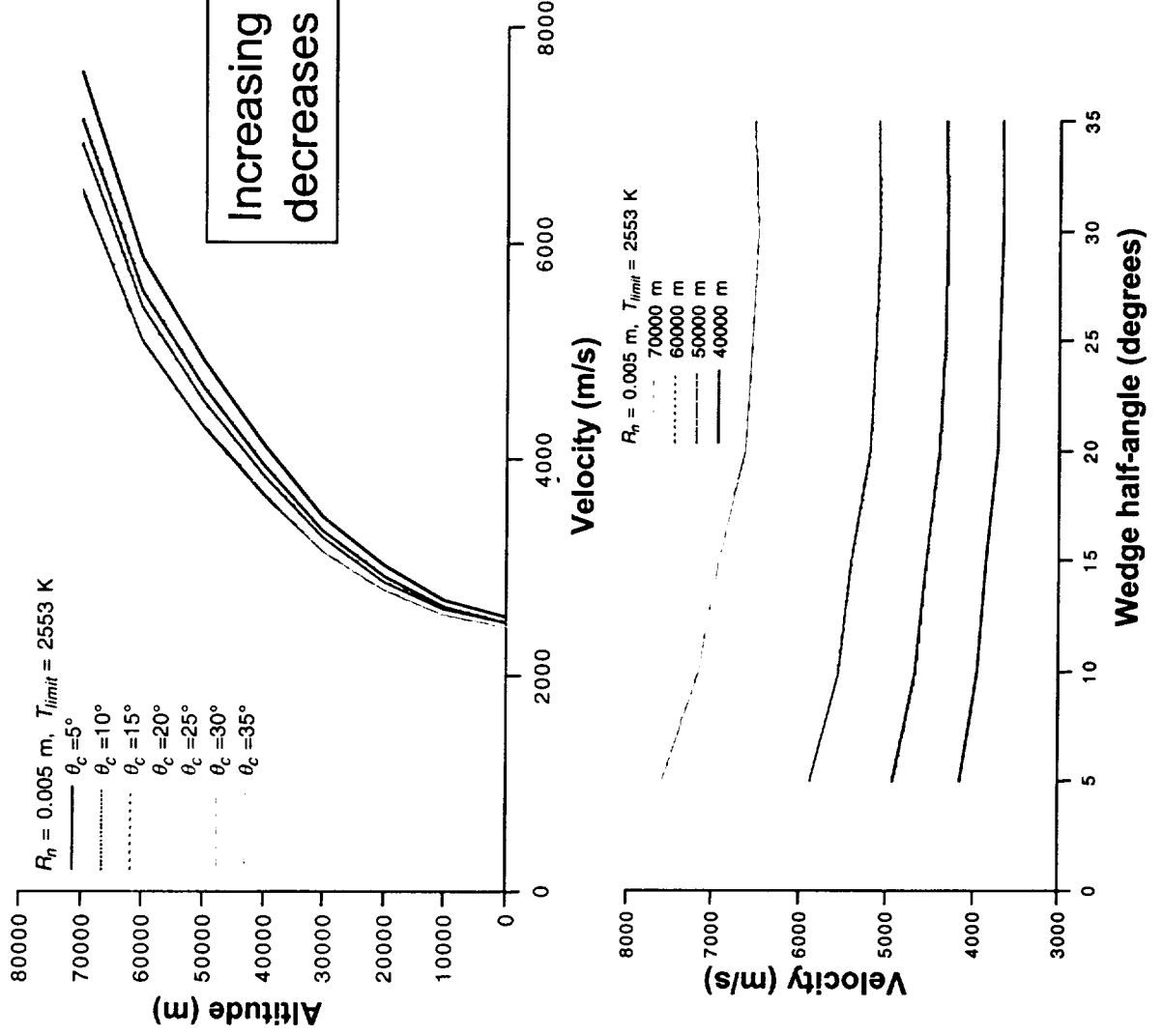


Sharp Nose

$$\dot{q}_{conv} = \dot{q}_{rad} + \dot{q}_{cond}$$

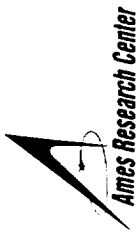


Wedge Half-Angle Sensitivity

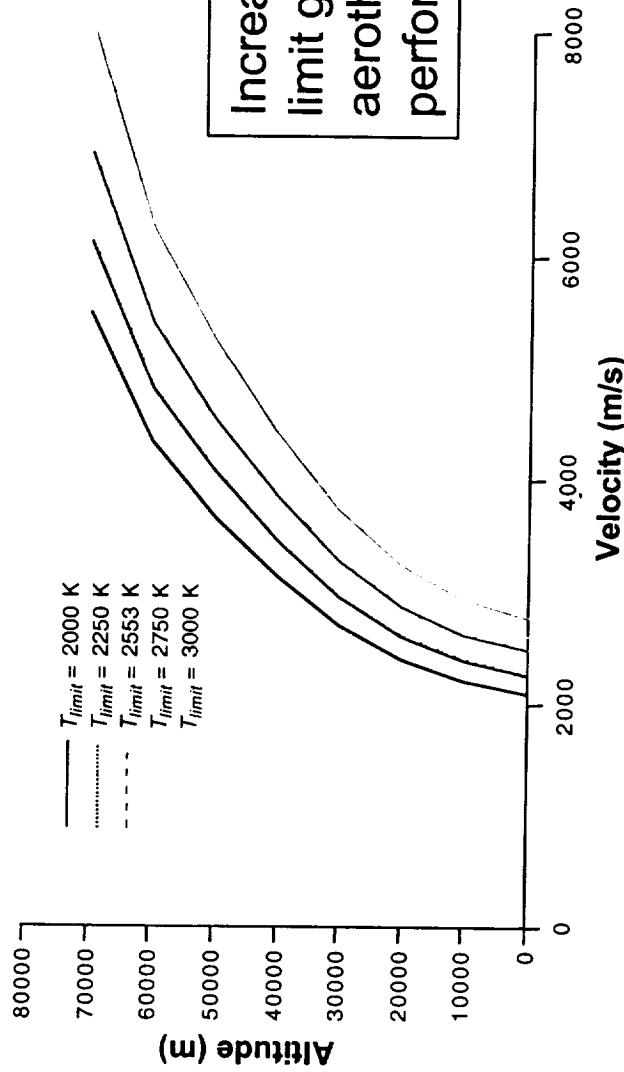


$T_{limit} = 2553 \text{ K}$



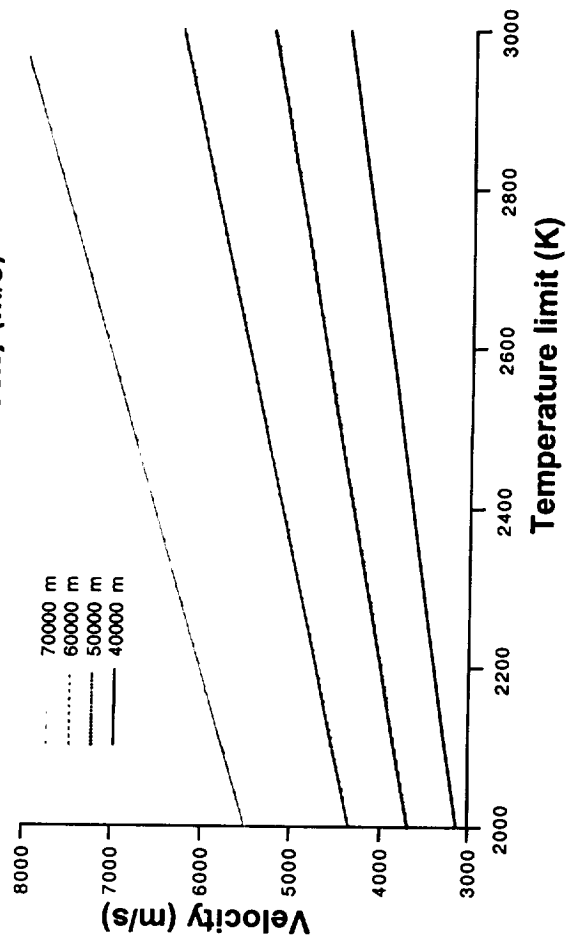


Temperature Limit Sensitivity



$$R_n = 0.005 \text{ m}$$

$$\theta_c = 15^\circ$$





Interest in UHTCs for Aerospace

Applications Initiated Over Thirty Years Ago

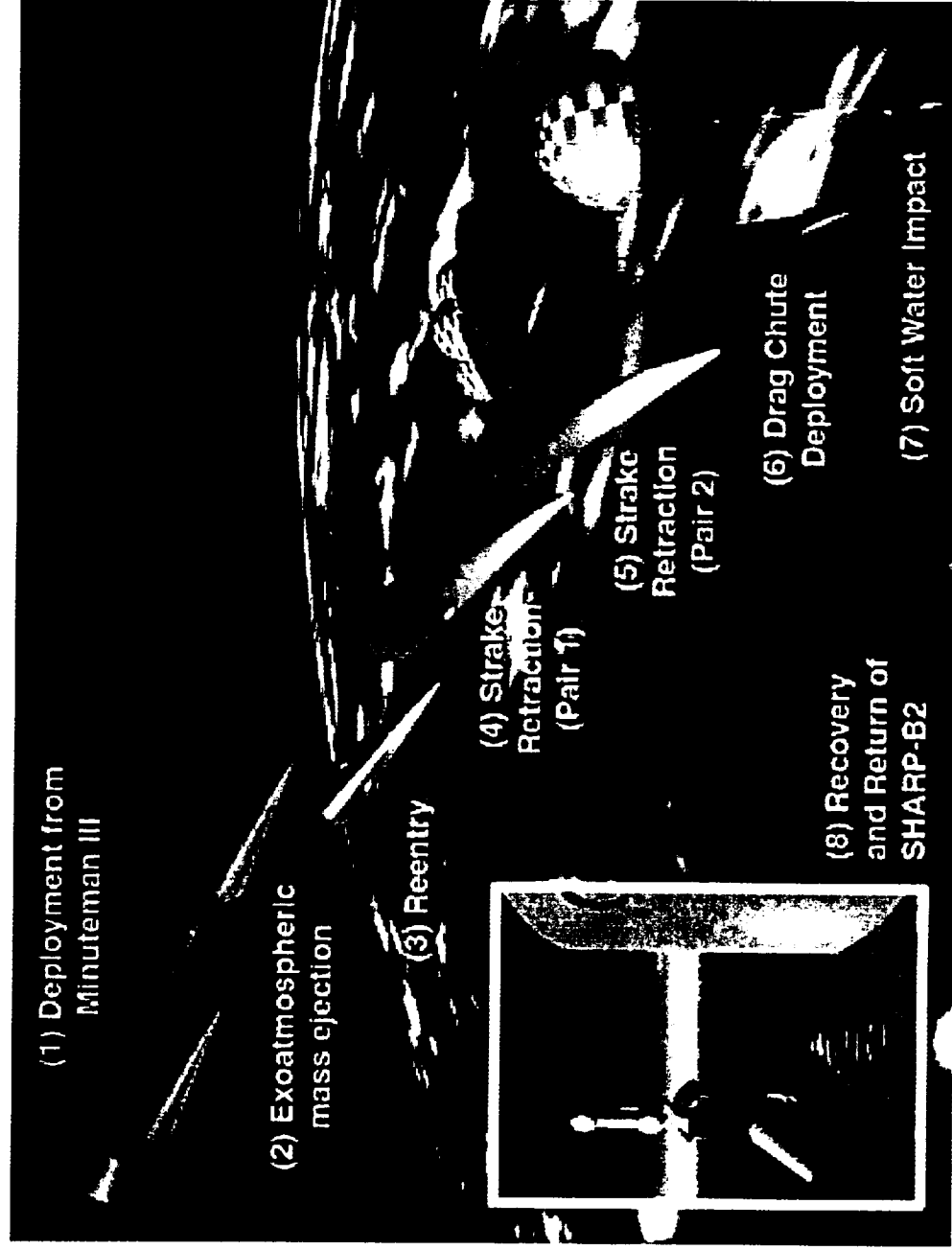


- Based on work performed by ManLabs Inc. in the 1960's and 1970's for the Air Force
- In the early 1990's Ames began investigating these materials for sharp leading edge applications.
 - Ground based research: initial materials development, arc-jet testing, computer modeling, etc.
 - SHARP-B1(1997) and SHARP-B2 (2000) ballistic flight experiments





Missions Like SHARP-B2 Provide a Method to Evaluate Materials in a True Hypersonic Reentry Environments





Much UHTC Research and Development Has Focused on Three Compositions

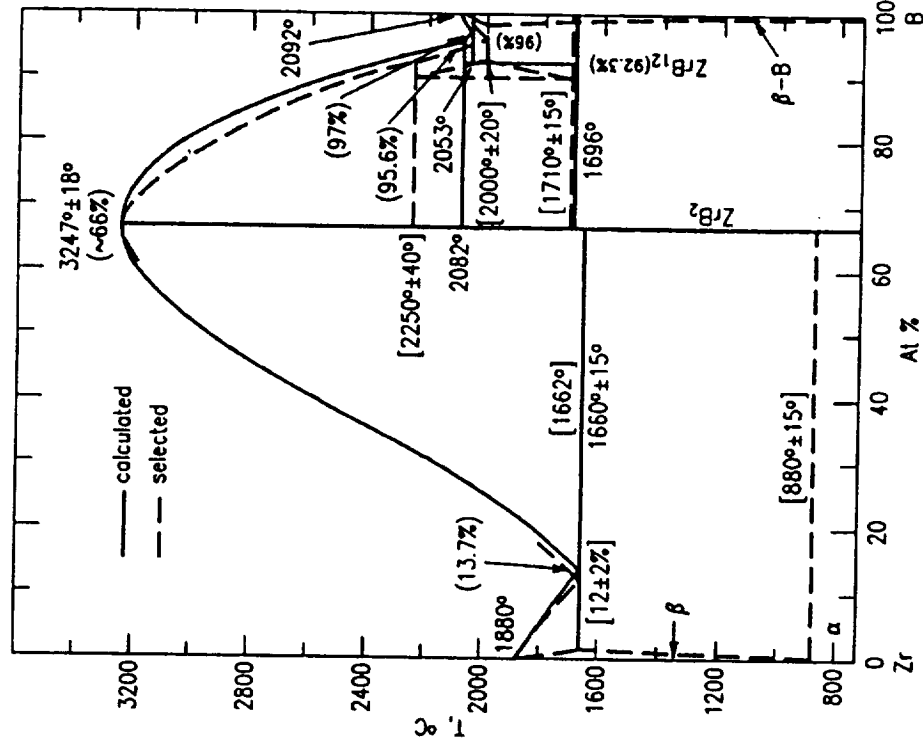


- Compositions:
 - $\text{HfB}_2/20\% \text{ SiC}$
 - $\text{ZrB}_2/20\% \text{ SiC}$
 - $\text{ZrB}_2/30\% \text{ C}/14\% \text{ SiC}$
- Based on compositions investigated by ManLabs Inc.
- Base material is the diboride with SiC particles and/or C flakes
- Materials were hot pressed
- Recent materials have been processed using external vendors





Stoichiometric ZrB_2 is a Line Compound That Melts at 3247°C

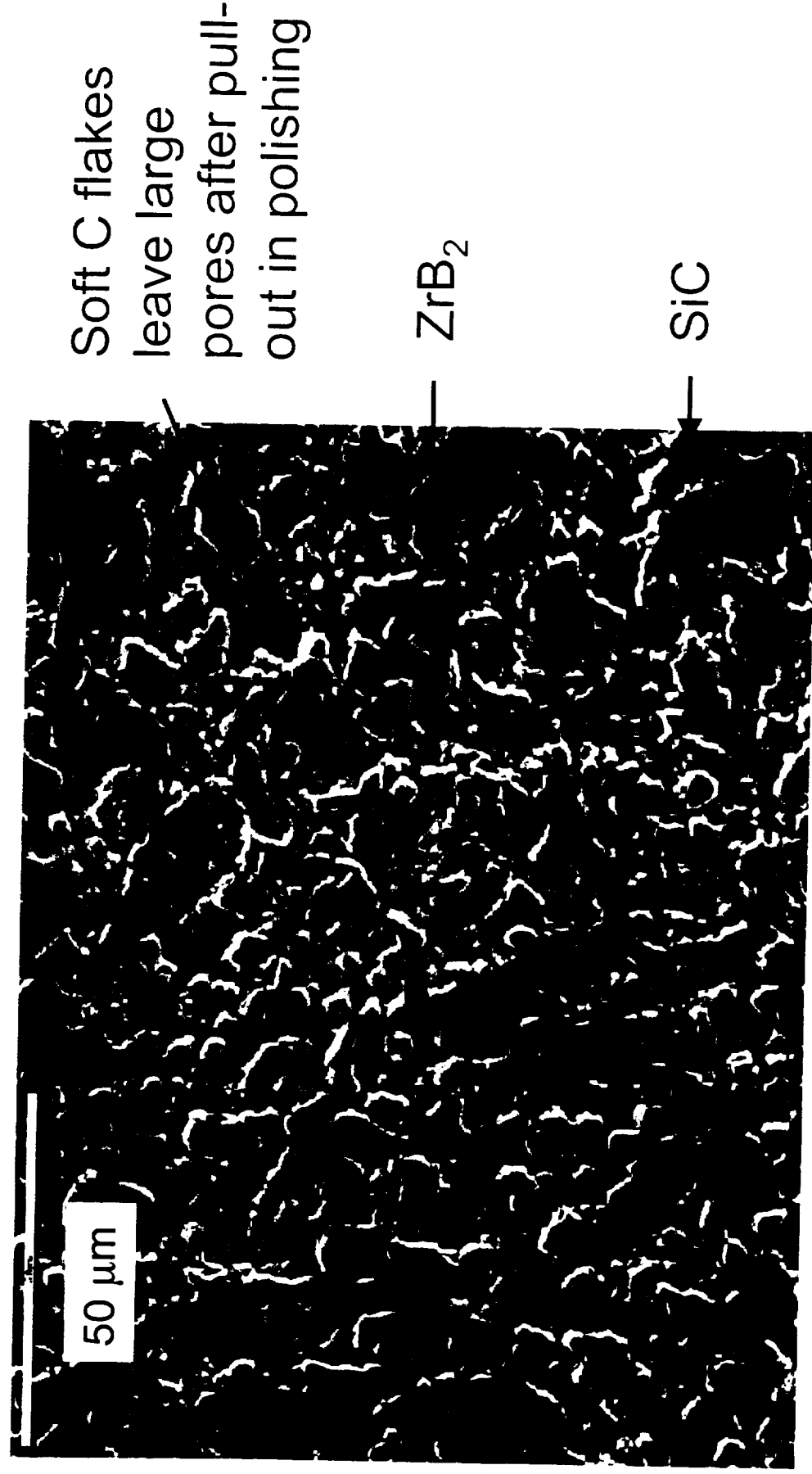
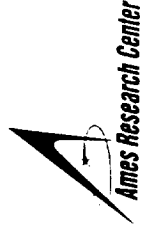


Off-stoichiometry compositions will contain free boron or zirconium



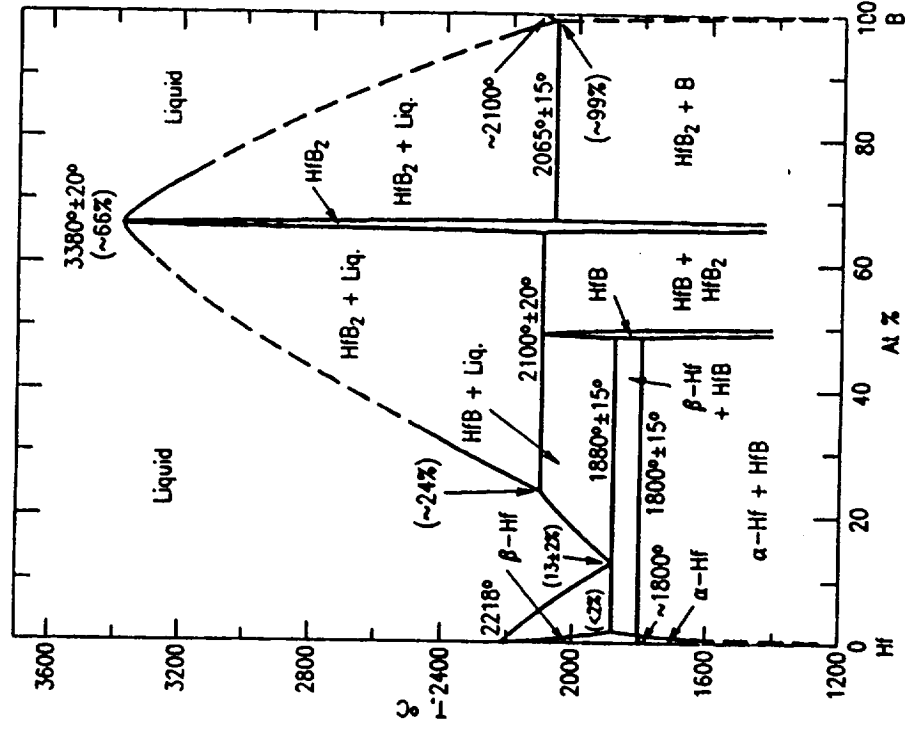


Scanning Electron Micrograph Shows Multiple Phases in ZrB_2 -30%C-14% SiC Composite

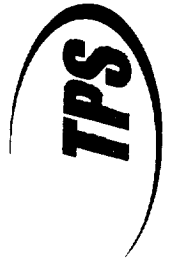




HfB₂ Has a Narrow Range of Stoichiometry With a Melting Temperature of 3380°C

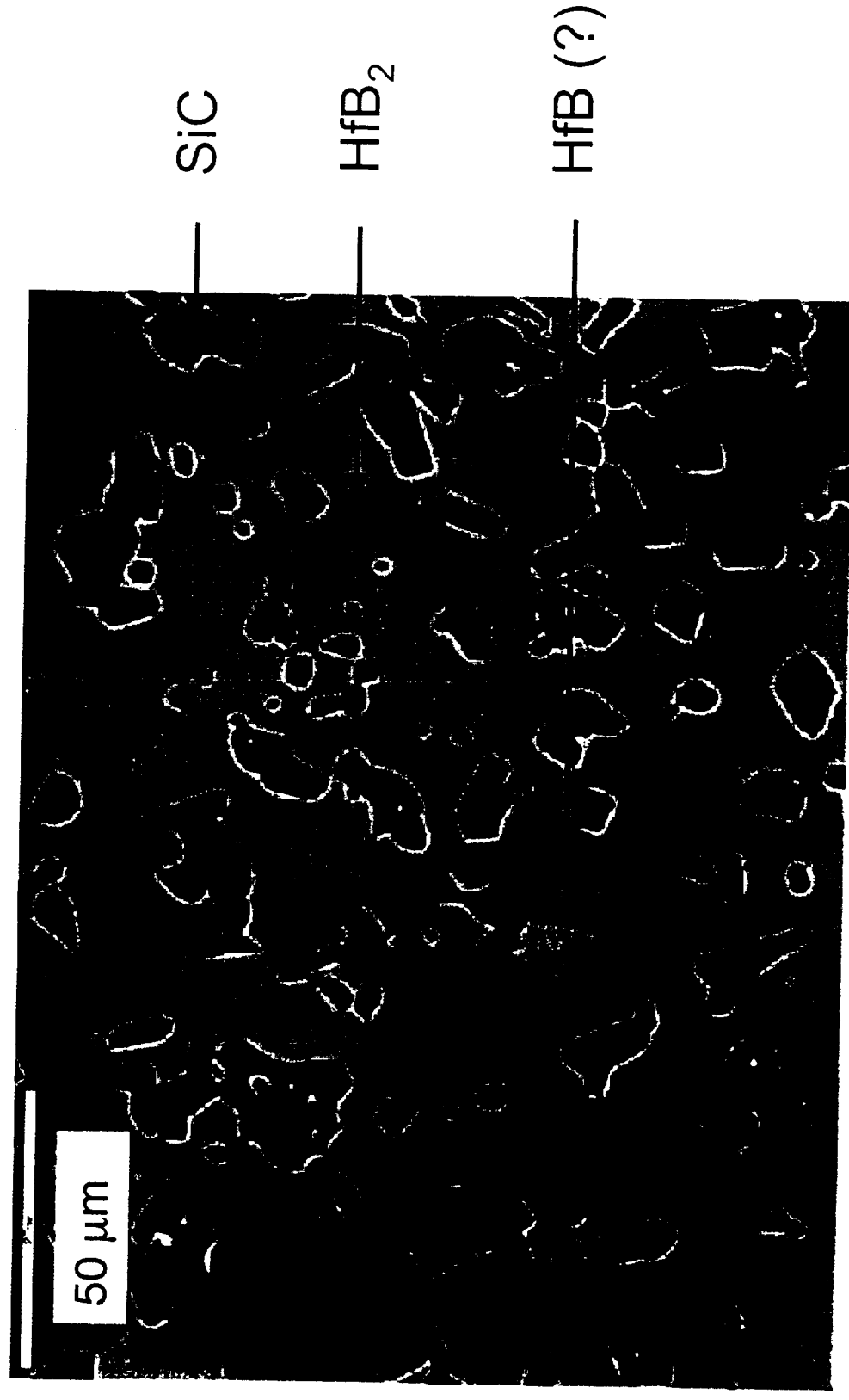


Compositions
deficient in
boron will
contain HfB and
HfB₂



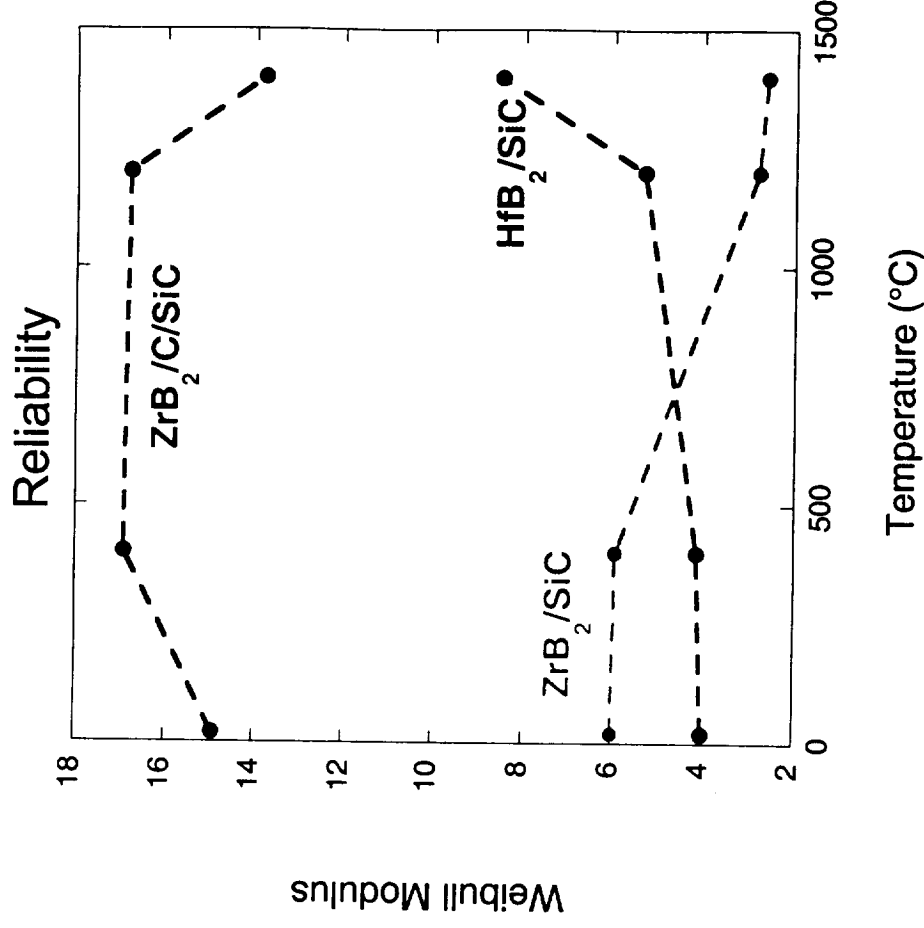
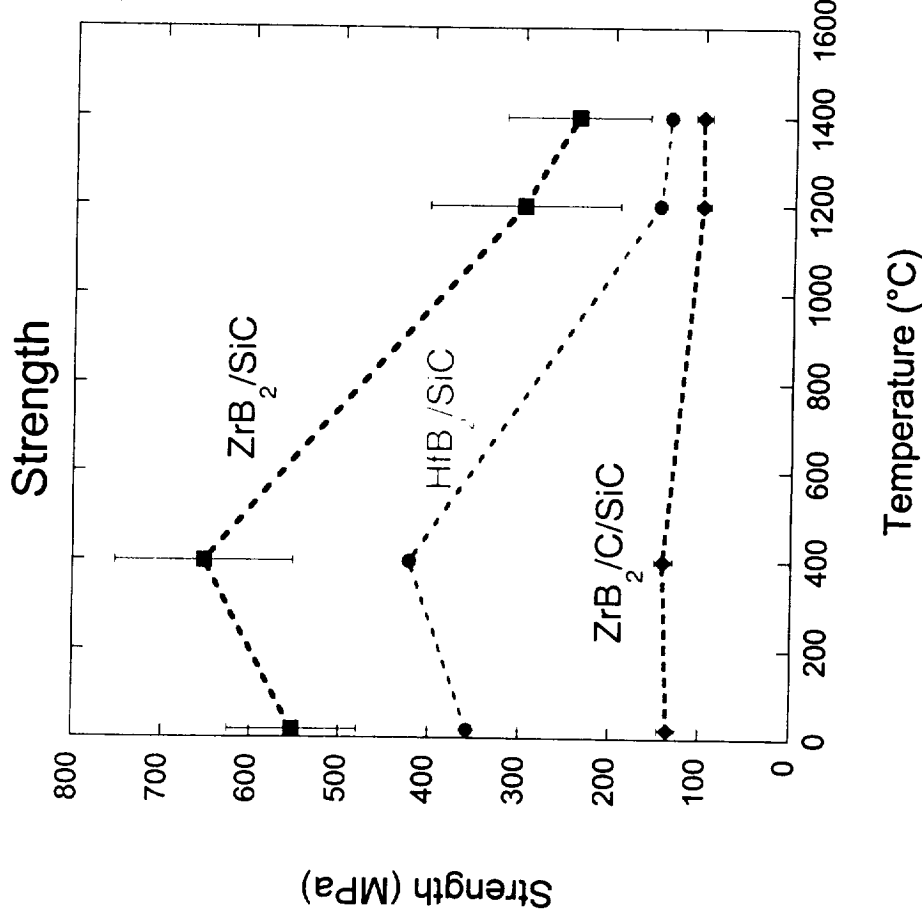


Scanning Electron Micrograph Shows Multiple Phases in HfB₂-20% SiC UHTC





UHTC Strength and Reliability



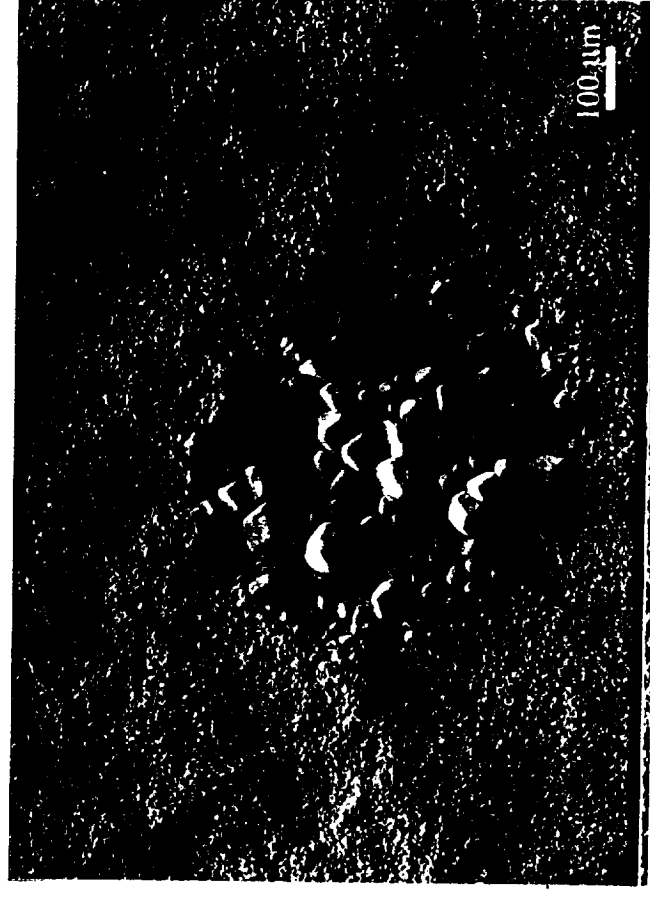
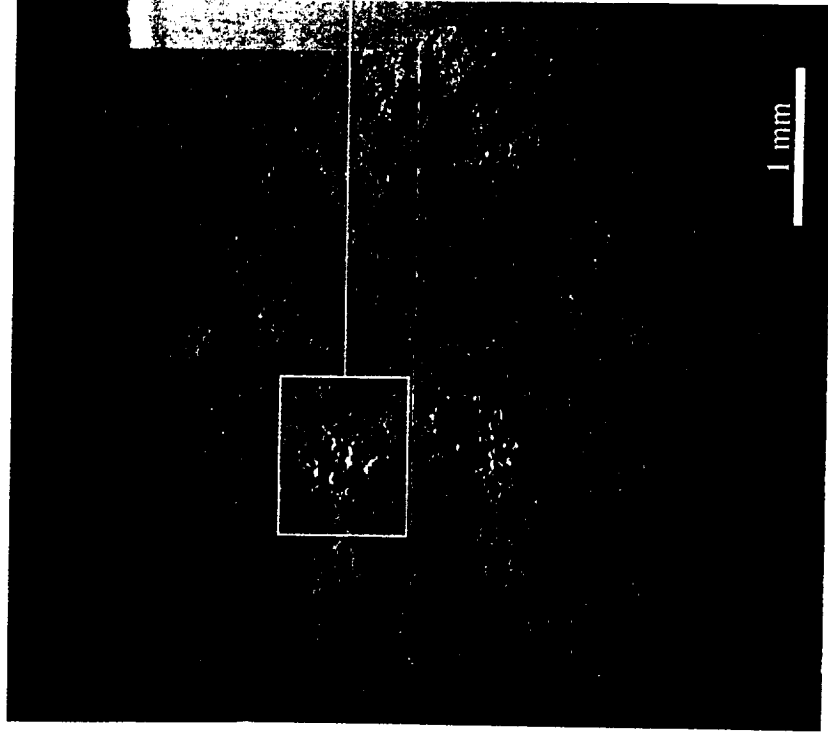
- The strength of ZrB₂/SiC and HfB₂/SiC materials show a significant temperature dependence.
- Current materials show relatively low reliability.
- ZrB₂/C/SiC material has a very low strength resulting in a perceived high reliability.



Large Processing Defects Are Observed



HfB₂/SiC Flexural Bar: $\sigma = 75 \text{ MPa}$, $T = 1200^\circ\text{C}$



- Large grain HfB₂ agglomerates present in microstructure due to incomplete mixing.

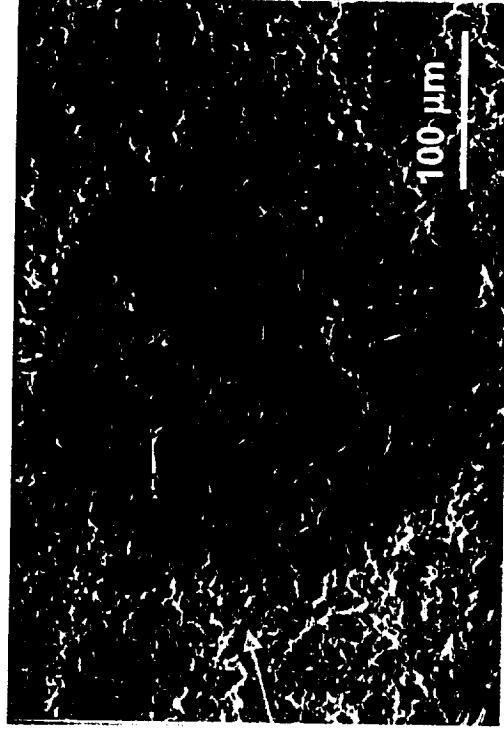
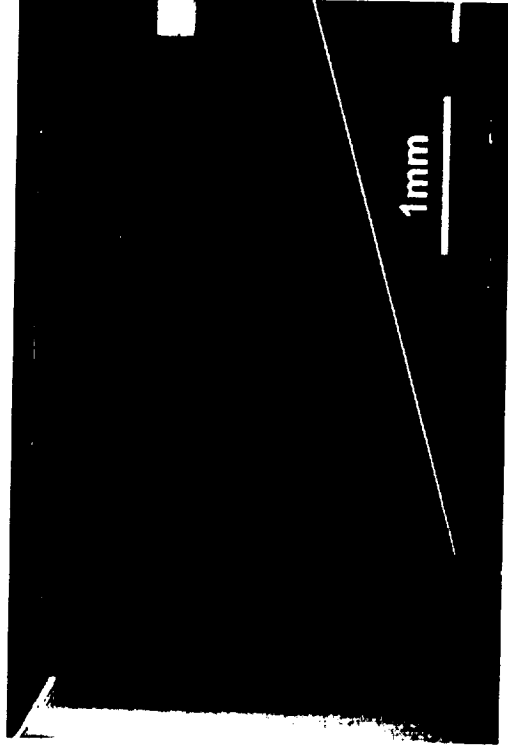
Source: Southern Research Institute



Processing Optimization Necessary



HfB₂/SiC Flexural Bar: $\sigma = 227$ MPa, $T = 21^\circ\text{C}$

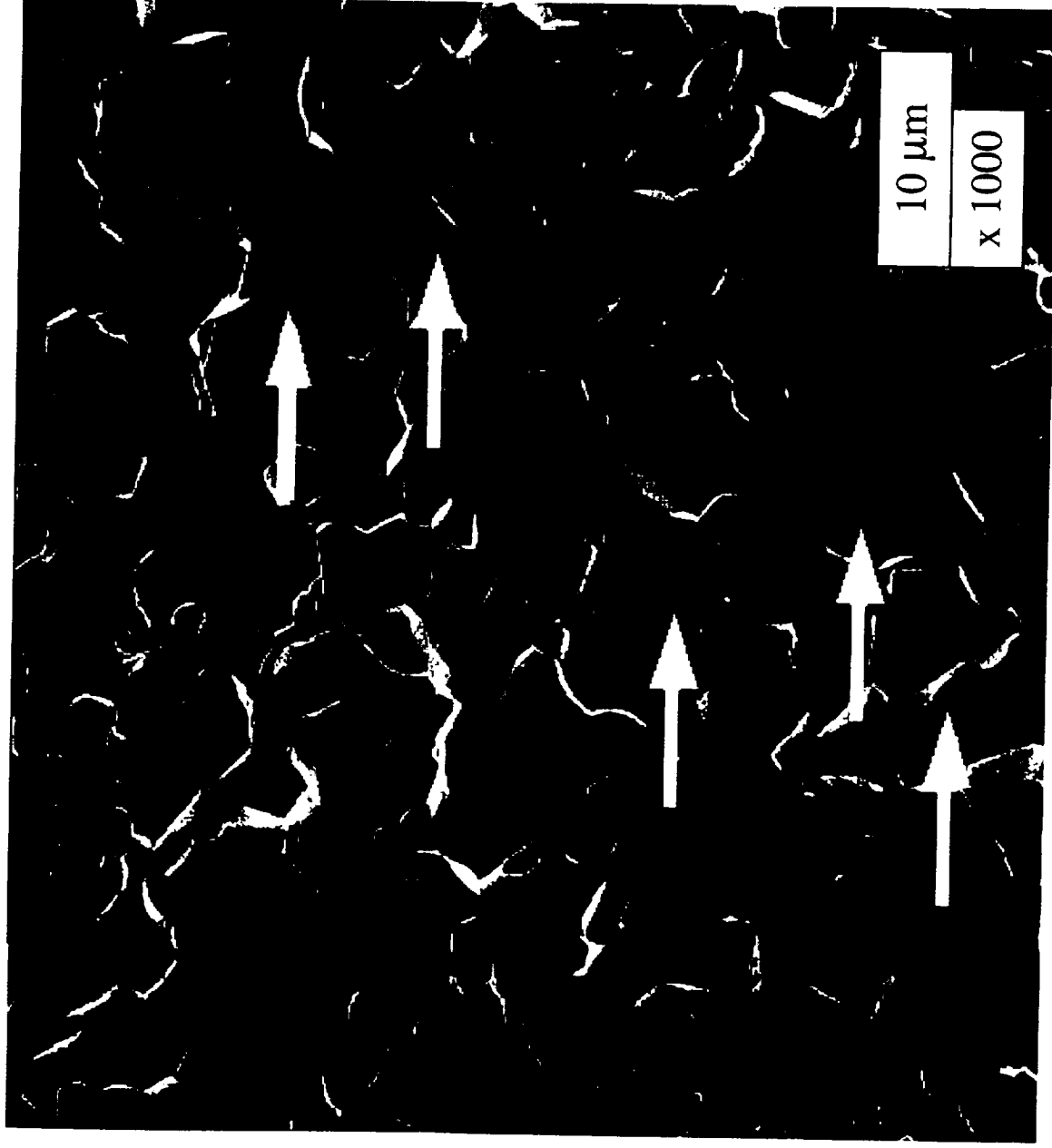


- SiC agglomerates present in microstructure (inhomogeneous)
 - Powder preparation is critical to ensure microstructural homogeneity
- SiC particles serve two functions:
 - Provides oxidation resistance at intermediate temperatures
 - Refines microstructure and reduces exaggerated grain growth





Higher Magnification SEM Images Show HfB₂ Test Sample



- Trans- and Inter-Granular Fracture
- Silicon Carbide Agglomerates

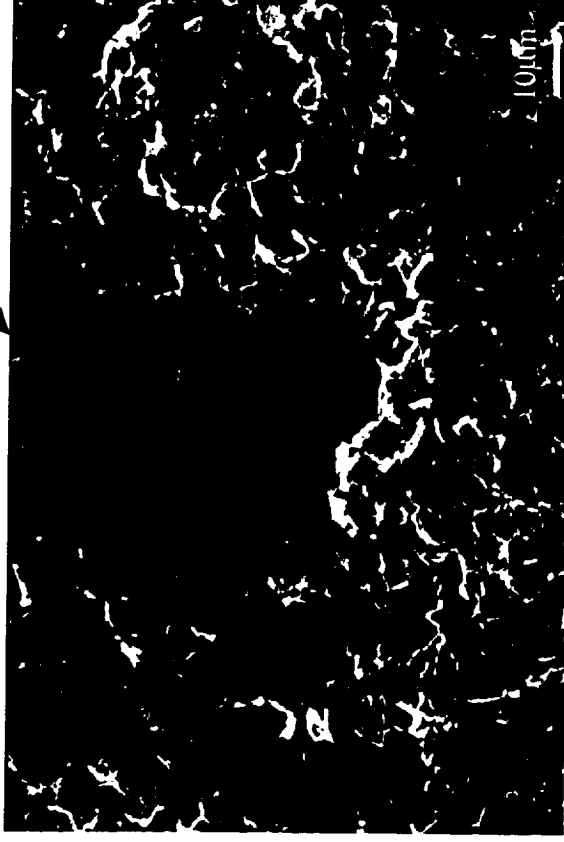


Analysis of Fracture Surfaces Shows Failure Origins to be Processing Flaws



ZrB₂/C/SiC Composite:

Large graphite agglomerate

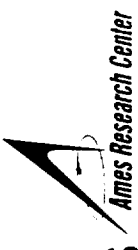


- Inclusions
- Machining damage
- Agglomerates





Characterization of Grain Boundaries Is Necessary to Improve Material Properties

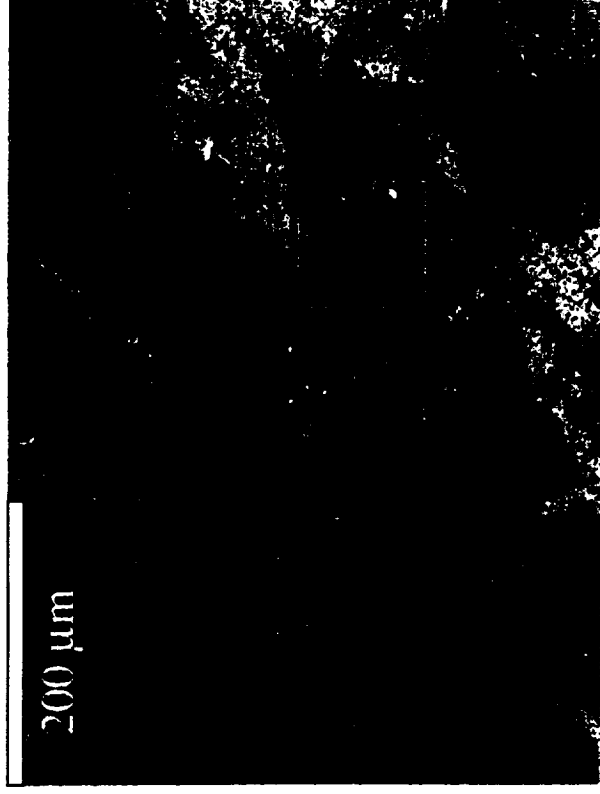


- In order to optimize properties we need to improve our understanding of:
 - sintering mechanisms
 - oxidation mechanisms
 - creep mechanisms
- }
- Influenced by:
- grain size
 - grain boundary composition
- Requires in-depth microstructural characterization
 - Collaboration with University of New Mexico on characterization of grain boundaries using electron microscopy (on-going)
 - Using their expertise to understand the role of the GB composition on sintering, creep, oxidation, etc.



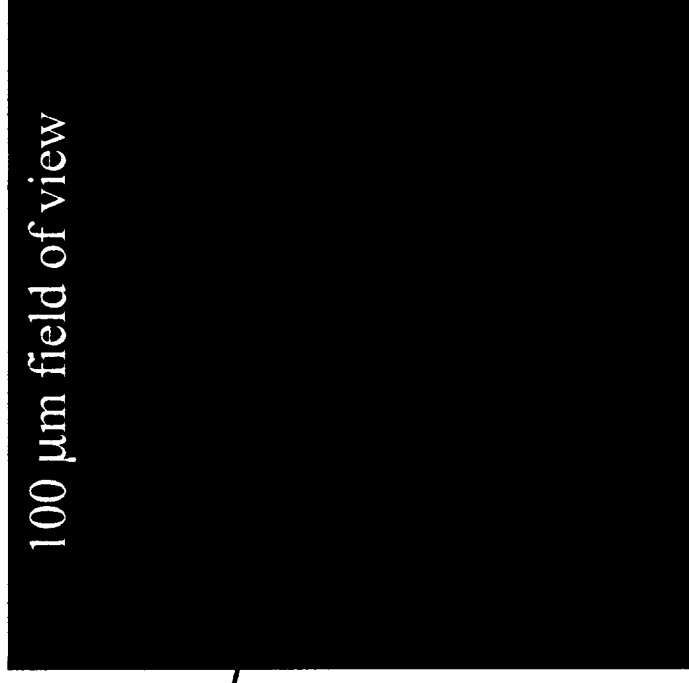


Compositional Mapping of Polished HfB_2 -SiC Surface



Green = SiC
Blue = HfB_2

100 μm field of view



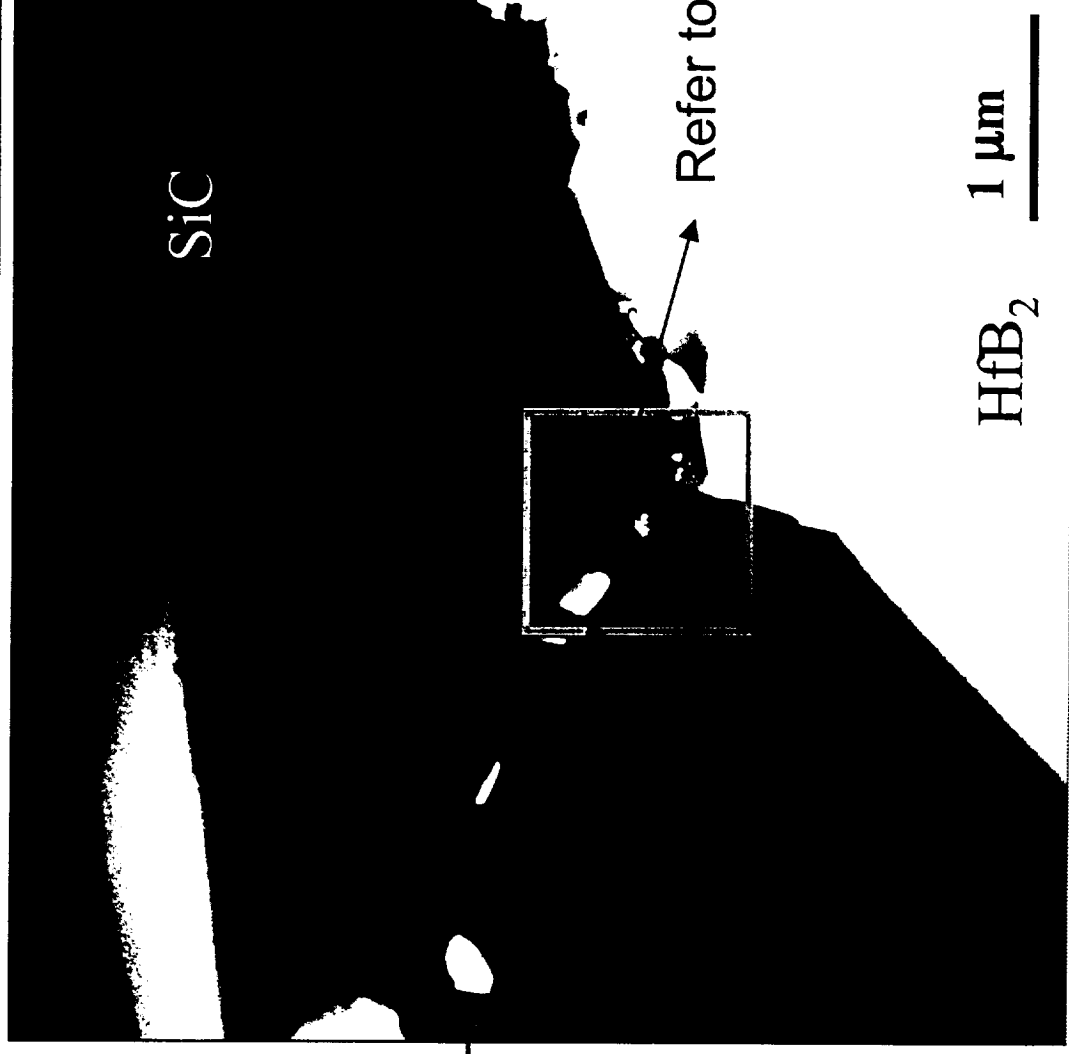
- Low mag polished section shows only SiC and HfB_2



TEM Image of SiC-SiC-HfB₂ Junction



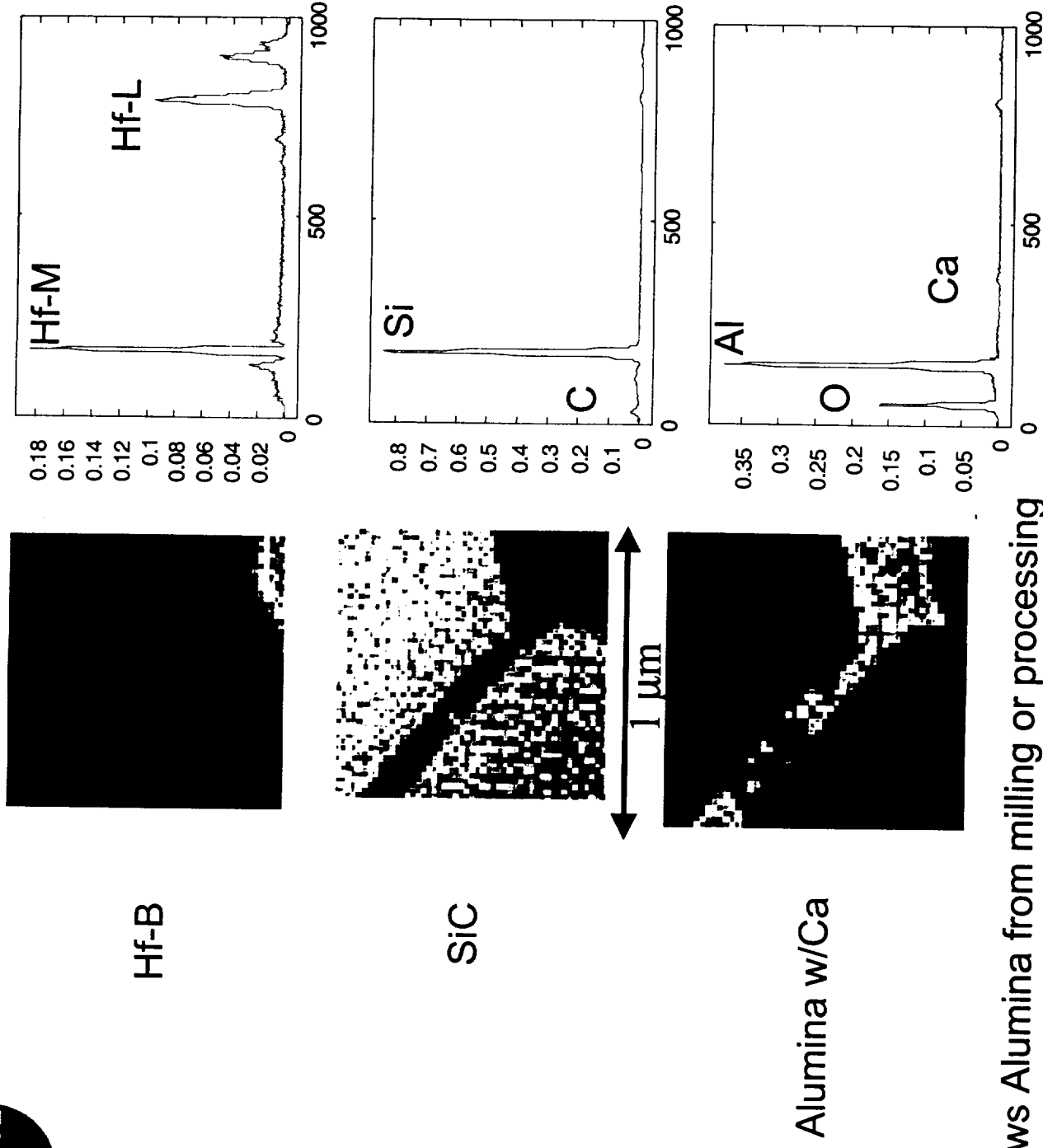
- White particles on grain boundaries are HfB₂





Compositional Maps of SiC-SiC-HfB₂ Grain Boundary Junction

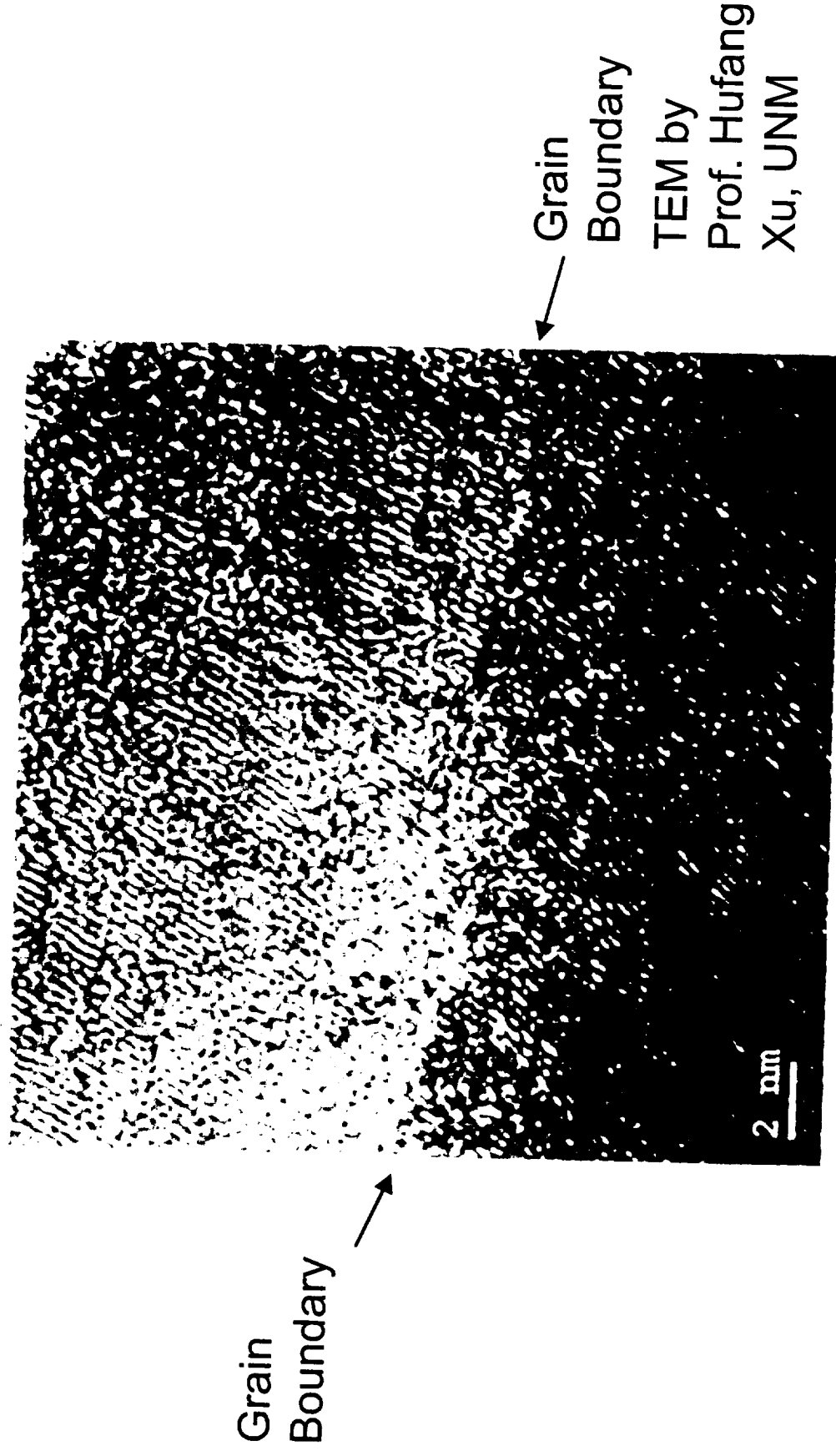
Ames Research Center



- Shows Alumina from milling or processing
- Impurities probably come from milling or processing



Atomic Resolution TEM Shows HfB_2 - HfB_2 Grain Boundary in HfB_2 -20% SiC UHTC



- No significant amorphous grain boundary phase observed